Department of Energy
Review Committee Report

on the

R&D Review

of the

SUPERNOVA/ ACCELERATION PROBE (SNAP) EXPERIMENT

July 2002

EXECUTIVE SUMMARY

On July 9-11, 2002, a Department of Energy (DOE) Committee conducted a review of the research and development (R&D) program of the proposed SuperNova/Acceleration Probe (SNAP) experiment at Lawrence Berkeley National Laboratory (LBNL). At the request of John O'Fallon, Director of the Division of High Energy Physics (HEP) in the DOE Office of Science, the review was conducted and chaired by Daniel Lehman, Director of the Construction Management Support Division, DOE Office of Science.

The Committee consisted of seventeen scientific and engineering experts in the fields of High Energy Physics, Astrophysics, Astronomy, and space flight. The focus of the review was on the SNAP R&D program in its current pre-conceptual design phase and its plans to get to Conceptual Design. In addition, the SNAP team also presented their responses to the requests for trade-off studies made by the January 2001 DOE review committee. The charge to the committee was to conduct an integrated examination of each subsystem, as well as assessing the technical progress overall, and the cost, schedule, and management planning of the R&D program, in the context of the entire proposed experiment.

The scientific objective of SNAP is to understand the nature and origin of the recently (1998) discovered "Dark Energy" causing the acceleration of the expansion of the universe. The experiment is designed to precisely measure the history of the accelerations and decelerations of the expansion of the universe from the current epoch back to approximately ten billion years ago.

The finding of Dark Energy is of central importance to High Energy Physics in its mission to explore the fundamental nature of matter, energy, space, and time. This mysterious Dark Energy does not fit into the current model of fundamental matter and energy. Further study of this dominant energy in the universe will address profound issues at the heart of both cosmology and High Energy Physics and will be of utmost importance to the understanding of the physical laws and contents of the universe.

Using the universe as a laboratory, the SNAP experiment is designed to discover and measure the properties of several thousand type Ia supernovae (SNeIa) to a precision and distance back in time unattainable from the ground. These supernovae can be used as "standard candles" and provide the most direct method of uncovering the nature of Dark Energy. The design is for a two-meter wide field telescope with an approximately half-billion-pixel CCD (charge-coupled device for optical wavelengths) and HgCdTe (Mercury Cadmium Telluride detectors for near infrared wavelengths) camera. A spectrograph will provide follow-on measurements of the discovered supernovae.

The Committee assessed whether the proposed project meets the scientific objectives for determining the expansion history of the universe and fully probing the nature of the Dark Energy and if the proposed instrument is able to carry out these objectives. Based upon their review, the Committee reported that "the need for a space based large field of view mission like SNAP to elucidate the nature of Dark Energy via the study of Type Ia supernovae has been convincingly established" and that "the proposed instruments and observing strategy is appropriate and sufficient to carry out the scientific objectives of the mission."

It was recommended that the detailed trade-off studies and simulations presented at the review be published as soon as practical for the benefit of the wider community. In addition, the Committee recommended that the SNAP team study weak lensing and other scientific topics relevant to cosmological parameters that are potentially accessible by SNAP in order to evaluate their possible inclusion in the SNAP program.

In their detailed review of the instrument concept, the Committee assessed the technical aspects and major risks of the R&D plan. The instrument package being developed for SNAP was regarded as "the most ambitious detector focal plane ever proposed, for ground or space" and was felt to be the highest risk item of the experiment. The Committee was impressed with the quality of the LBNL CCD team, though "the CCDs have not reached full maturity". The infrared team is just getting started and the Committee commented that the team should ride on the back of larger efforts currently underway for other experiments while developing expertise and an infrared testing facility. The spectrograph design and team are good, with no showstoppers found. The electronics development was well planned and adequately staffed. Specific recommendations regarding particular instrument designs, plans or studies were made. The Committee felt that the CCD team should be strengthened and that the infrared detector development effort needs to be strengthened, if necessary by bringing in collaborators with experience in infrared detectors. Overall, the Committee recommended that "the development of detectors should be given highest priority of the entire SNAP project during the R&D phase."

Minor recommendations regarding data transmissions and the attitude control system for the spacecraft were made by the Committee. The telescope design planning was found to be on track with no changes needed. It was felt that SNAP should take advantage of software work being done elsewhere and that a complete, prioritized list of software tasks should be developed.

The cost estimate for the planned R&D program appeared to be appropriate for a project in this phase and the contingency of 34 percent was adequate, though not generous. Major risks and uncertainties appear to be adequately identified. It was noted that the significant contributions of the LBNL Laboratory Directed Research and Development (LDRD) funds will not be able to continue, due to the three year limit. The Committee recommended that the project "pursue the requested funding through the DOE/HEP program office and other potential funding sources."

The management team and structure was found to be well matched, adequate, and appropriate for the planned R&D phase. The level of engineering support was excellent. Management tools for cost and schedule development were found to be adequate. Roles and responsibilities, as well as R&D deliverables are well defined. The Committee felt that the SNAP team should establish a laboratory-to-laboratory agreements with the French groups as soon as reasonable. The strong support and oversight provided by the LBNL management was recognized and strongly encouraged to continue. It was recommended that SNAP management establish discussions with the funding agencies and continue building the collaboration to enlist groups with important interest and experience.

Overall, the Committee recommended that "the R&D effort necessary to move this project forward should be pursued with all possible speed" and that SNAP is "ready to go to CD-0, when deemed appropriate by DOE."

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1. INTRODUCTION

On July 9-11, 2002, the Department of Energy (DOE) conducted a review of the research and development (R&D) program of the proposed SuperNova/Acceleration Probe (SNAP) experiment at Lawrence Berkeley National Laboratory (LBNL). The Division of High Energy Physics (DHEP) has programmatic oversight responsibility for the proposed SNAP experiment. The Director of the DHEP, John O'Fallon, requested that the Director of the Construction Management Support Division, Daniel Lehman, conduct and chair the review.

The first direct experimental evidence for an accelerating universe, driven by an unknown energy that permeates space, was measured recently (1998) by two scientific groups (the Supernova Cosmology Project and the High-z Supernova Search) using ground-based measurements of the Hubble diagram from type Ia supernovae (SNeIa). Members of the Supernova Cosmology Project, centered at LBNL, have continued working on second-generation measurements using ground- and space-based telescopes (e.g., the Hubble Space Telescope). In addition, the LBNL-led team initiated the collaboration that proposed SNAP as a dedicated third generation follow-on experiment to further explore the nature of the Dark Energy.

Along with supernovae measurements, cosmic microwave background and large-scale structure measurements also indicate the presence of Dark Energy. The current supernovae results, together with these results imply that about 65 percent of the content of the universe is composed of this mysterious Dark Energy. The rest is composed of about 30 percent Dark Matter, leaving only five percent known matter. However, the cosmic microwave background and large-scale structure methods do not allow measurements of the nature of the Dark Energy, including whether it's a constant or has varied over time.

SNAP is a proposed, space-based experiment designed to discover and precisely measure thousands of SNeIa. From the data collected, the SNAP collaboration will be able to precisely measure the equation of state of the universe, measure the history of its accelerations and decelerations and to study the nature of dark energy, which is causing the current acceleration of the expansion of the universe.

Using supernovae measurements, SNAP will be able to measure the equation of state, w, of the universe as well as how it varies over time, w'. This detailed knowledge will distinguish between different theoretical models for the nature of the Dark Energy. For $w = -1$ and constant, it implies that Einstein's inclusion of a cosmological constant in General Relativity is correct and there is new knowledge of the quantum vacuum. For other values and variations over time, it could imply a new energy in the universe or a new understanding of gravitation beyond General Relativity. SNAP will be able to differentiate between these possibilities, as well as other theoretical models for the Dark Energy, and lead to deeper understanding of the universe.

The main feature of the proposed apparatus is a two-meter, wide-field telescope with a half-billion-pixel optical and infrared camera launched into earth orbit. The SNAP experiment began its pre-conceptual planning phase in 1999. It has been supported significantly both by R&D funds from DOE and the Laboratory Directed Research and Development funds from LBNL.

The SNAP experiment has already undergone a number of focused reviews. An initial review of SNAP was held by the Scientific Assessment Group for Experiments in Non-Accelerator Physics (SAGENAP) panel in February 2000. At this review, the scientific goals of the experiment were "deemed extremely important." A blue-ribbon panel review of the R&D program was conducted by the Division of High Energy Physics in January 2001. The review panel included sixteen scientific and engineering experts from the fields of High Energy Physics, Astrophysics, and Astronomy. The Committee reported that the "SNAP science goals are excellent and address fundamental questions in particle physics and cosmology." They concluded that further trade-off studies needed to be done before the next review and recommended that DOE encourage and support substantial simulation and trade-off studies in this period. The joint DOE/National Science Foundation High Energy Physics Advisory Panel 2001 Subpanel released their report in January 2002. They endorsed R&D funding for SNAP from the high-energy physics program. In addition, they recommended that the full project, if approved, include significant National Aeronautics and Space Administration (NASA) participation in the construction and launch of the instrument. The report by the National Research Council's Committee on the Physics of the Universe, released in April 2002, recommended three new non-prioritized initiatives, one of which is to determine the properties of dark energy. The Committee recommended that "NASA and DOE work together to construct a wide-field telescope in space to determine the expansion history of the universe and full probe the nature of the dark energy". The NASA Structure and Evolution of the Universe 2003 roadmap committee is now on record endorsing the science goal of measurement of dark energy (though it did not call out a specific mission design). The SAGENAP panel reviewed the SNAP experiment again in March 2002 and the report will be released in August 2002. Recommendations from panels and previous reviews along with the progress of the SNAP R&D program have developed to a stage where an extensive review is necessary and forms the basis for the current review.

The focus of the current review was on the SNAP R&D in its current pre-conceptual design phase and its plans for the future conceptual design phase. In addition, the Committee was asked to comment on the effectiveness of the SNAP team in moving the project to conceptual design. They reviewed SNAP in the context of the entire proposed experiment. The Committee was asked to carry out an integrated examination of each subsystem; the technical progress overall; and cost, schedule, and management planning of the R&D program.

The Committee (see Appendix B) included seventeen scientific and engineering experts working in the fields of High Energy Physics, Astrophysics, Astronomy, and space flight. In addition to their scientific and engineering expertise, these Committee members had specific areas of expertise applicable to the SNAP experiment including space systems, telescopes, electronics, optical and infrared sensors, large-scale computing, and project management. Observers were in attendance from both the DOE and NASA agencies.

The Committee reviewed the detailed presentations made by the collaboration members on the scientific and technical aspects of the experiment. In addition, they reviewed the collaboration's responses to requests made by the January 2001 Review Committee. The Committee provided recommendations to the SNAP collaboration and to the agencies during the closeout of the review. Their evaluations in terms of findings, comments and recommendations are contained in this report.

The report begins with a discussion of the science requirements for the SNAP experiment. The sections that follow (space systems, telescope, instrument, ground segment, and computing) are organized according to major subsystems in the work breakdown structure (WBS). The final sections cover cost, schedule, funding, and management of the entire planned R&D phase. Appendices at the end of the report show the charge to the Committee (Appendix A), the review participants (Appendix B), the agenda (Appendix C), cost tables and schedule charts (Appendix D), and funding tables (Appendix E). Recommendations resulting from this review are included at the end of each of the sections.

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2. SCIENCE REQUIREMENTS (WBS 1.2, 2.5)

2.1 Findings

2.1.1 Scientific Motivation

The scientific motivation for the SNAP mission was presented to the Committee in some detail. The focus of the mission is to study the cosmological parameters governing the expansion rate of the universe via the detailed study of Type Ia Supernovae (SNeIa).

The SNeIa are strikingly similar violent explosion events whose physics can be analyzed in detail from their intensity and spectrum as they brighten and fade. Most observed SNeIa have nearly the same peak luminosity, and the variations that do occur are correlated with other observables and can be calibrated to approximately five percent. Thus these SNeIa serve as nearly ideal "standard candles" and the observed variation-corrected peak brightness (magnitude) is then a measure of the distance to the supernova.

The wavelengths of the photons from the supernova are stretched or "redshifted" in exact proportion to the expansion of the universe during the time that the photon travels to earth. Thus the comparison of the peak brightness (magnitude) and the redshift of the supernova provide a measurement of the changing rate of expansion of the universe: the observed magnitude indicates the distance, and hence the time back, to the supernova explosion, while the redshift measures the total relative expansion of the universe since that time.

The SNAP mission is designed to obtain a Hubble diagram (peak magnitude *vs* redshift plot) for a large and well-studied sample of supernovae, looking back in time over two-thirds of the age of the universe. With such a history of the expansion rate, it should be possible to determine the contributions of the decelerating and accelerating energy densities that make up the universe: the mass energy density $\Omega_{m,}$ the vacuum energy density Ω_{Λ}, and/or other yet to be studied "dark energy" components. Such a detailed study can also measure the properties of this new vacuum energy or dark energy, usually referred to as the equation of state.

2.1.2 The SNAP Mission

The SNAP mission utilizes a space-based, wide field visible and near infrared telescope of moderate aperture (2.0 m) to observe SNeIa up to cosmological redshifts of 1.7. These supernovae, which are the result of detonating carbon-oxygen white dwarfs, are excellent "standard candles" and serve as bright distance markers. Over the nominal four-year mission life, SNAP will observe over 2,000 supernovae over the redshift range 0-1.7. While the intrinsic brightness of an individual supernova may vary, the large number of observations and high quality spectra will provide sufficient data to characterize and renormalize the events by subclass and unambiguously establish the accelerating expansion of the universe and define the "dark energy" equation of state.

While current day supernova searches have sufficient sensitivity to observe the effects of acceleration, they are ultimately limited by the difficulty of ground-based infrared observations, continuous monitoring of the supernova fields and knowledge of the host environments for each of the supernova. Utilizing diffraction-limited space optics and a high Earth orbit that permits passive cooling of the focal plane, the SNAP mission has Hubble-class sensitivity in both imaging and spectroscopy, with a camera field of view over 200 times larger than Hubble. With a four-day cadence, the SNAP scans a 1.3 x 8 degree swath of the celestial sphere in nine overlapping filter bands from 350-1700 nm. These filters and the repeated observations permit the creation of continuous light curves in the important "rest-wavelength" bands established for supernova study and classification. Periodically, the scanning cadence is broken to obtain visible and near infrared (NIR) spectroscopy of each supernova when it is within a few days of peak luminosity (as estimated from the discovery lightcurves). The spectra will be used to classify each supernova within the various SNeIa subclasses and to provide estimates of such quantities such as metalicity, internal host reddening, and explosion energetics.

The success of the SNAP mission depends on superb control of systematic effects, both astrophysical and instrumental. The SNAP collaboration has established a target "floor" of 0.02 magnitudes (two percent) for the total residual of uncompensated systematic effects. This floor is several times lower than can be realistically met with alternative facilities but is essential to an adequate measure of the dark energy equation of state. Much of the SNAP mission design is devoted to addressing and compensating for potential systematic effects: the observing strategy, the layout of the focal plane filters, the establishment of photometric and spectroscopy markers, and the choice of target fields. The SNAP science team uses analytic techniques and simulators to verify that these steps are sufficient.

2.1.3 Simulations and Studies

In the development of major space-based and ground-based science missions, simulations and special science studies play a critical role in validating the mission concept and establishing requirements. The SNAP science team is developing two end-to-end simulations of the SNAP mission. Both start with a Monte Carlo selection of SNeIa events and their observable properties. The "light" from these supernovae pass through the host galaxy (extinction), the intergalactic medium and surrounding mass concentrations ("grey dust" and weak gravitational amplification), through the Milky Way (extinction) and reach the SNAP telescope. In SNAPFast, the first of the two simulations, the telescope and instrument package are represented analytically, with exposure time calculators based upon input mission parameters (optical quality, throughput, etc.) The result is a simulated lightcurve in each filter and a set of spectroscopic markers. The SNAP science team is developing a more detailed simulation of the observatory that will emulate the pixel-to-pixel responses of the camera and spectrograph. After simulating the science data for the entire four-year mission, the SNAP team passes the data through simulated operations and data analysis steps and ultimately produces a composite supernova Hubble diagram (magnitude *vs* redshift) and obtains values and estimated uncertainties of the dark energy equation of state using maximum likelihood techniques. By varying instrumental or astrophysical parameters and repeating the entire process, the SNAP science team can establish the importance of each parameter and modify the mission design accordingly.

The SNAP science team has also developed simulations of ground-based and space-based observatories such as the Large-aperture Synoptic Survey Telescope (LSST), Hubble, and the Next Generation Space Telescope (NGST). These simulations include such effects as seeing, atmospheric emission and absorption, weather, instrumental capabilities, and other observing constraints. By this technique, the science team can study whether individual SNAP capabilities can be provided by other facilities.

2.1.4 Response to the January 2001 DOE Review

The SNAP team presented in detail their responses to the issues and concerns raised and the recommendations made in the January 2001 DOE review report (see section 2.2.4).

2.1.5 Other Uses of SNAP

While the current experimental design is optimal for the SNeIa project, the wide field, 9 filter-band imager is a nearly ideal instrument for other important scientific studies, such as a weak-lensing survey. A weak-lensing survey could map the structure in the dark matter and measure its power spectrum. In addition, other important surveys such as a very deep and wide photometric redshift galaxy survey with morphology could be done.

2.2 Comments

2.2.1 The Importance of the Scientific Goals of the Mission

The evidence for cosmic acceleration is shaking the very foundations of fundamental physics. It focuses the spotlight squarely on the "cosmological constant problem" which has probably been the most challenging and awkward problem in theoretical physics ever since the development of field theory in the mid 20th century. The Supernova Cosmology Project (SCP) centered at LBNL was one of two collaborations (SCP and the High-Z Supernova Search) that recently published measurements of the apparent magnitude versus redshift relation of Type Ia supernovae. These measurements, together with other measurements of the cosmic microwave background (CMB) and galaxy clustering, provide strong evidence that the expansion rate of the universe is accelerating, rather than slowing down as might be expected for a matter dominated universe with attractive gravity. To explain an accelerating expansion rate one has to postulate, in addition to the yet to be observed "dark matter," a presently unobserved energy density, "dark energy" that fills space and has unorthodox properties like an effective repulsive gravity and negative pressure. (The pressure P is related to the energy density ρ by the equation of state $P = w\rho$, where w could be a negative constant less than $-1/3$, or could be a function of the redshift $w(z)$, parameterized as $w = w_0 + w' z$.) The main scientific goal of the SNAP mission is to collect a statistically significant sample of SNeIa with detailed enough information on each to carry out a definitive study of the properties of this mysterious new "dark energy."

Such a study will address profound issues at the heart of both cosmology and elementary particle physics. In the words of Professor David Schramm, to whose memory the recent National Research Council (NRC) Committee on Physics of the Universe (Turner Report) is dedicated:

> "The study of the very large (cosmology) and the study of the very small (elementary particle physics) is coming together."

The importance of the SNAP mission to cosmology is clear in that it can trace the expansion history of the universe. The SNeIa measurements will uniquely address issues at the very heart of particle physics in a number of ways. In an accelerating universe w has to be less than $-1/3$. If $w = -1$, exactly, the acceleration can be said to be due to a small but non-zero value of the cosmological constant Λ or a homogenous false vacuum energy. For other values of w there is a completely new form of energy density, dubbed "Dark Energy." A measurement of w by SNAP (and possibly others) will distinguish between these two possibilities.

If the acceleration is caused by the cosmological constant Λ, then particle physics is faced with a severe dilemma: naive expectations regarding the vacuum quantum fluctuations imply a cosmological constant term in Einstein's equations of general relativity with a value approximately 10^{120} times larger than the value of Λ implied from the cosmological measurements. This disagreement has profound implications for particle physics—some have called it the most significant problem known in modern physics. The understanding of this problem is at the heart of any attempts at unified theories that involve a quantum theory of gravity. There is some feeling that an exactly zero Λ could be explained by some as yet undiscovered symmetry law in nature. A small but non-zero value is very difficult to reconcile with any attempts at a fundamental theory such as string theory. Recent advances in formulating a quantum theory of gravity (e.g., string theory) have brought the problem even greater notoriety because these advances, despite achieving other impressive successes, have failed to improve the understanding of cosmological constant, an understanding that is essential for any true fundamental theory of gravity and matter.

If *w* turns out to be negative but not –1, then particle physics is faced with a completely new form of energy density, the Dark Energy, with negative pressure and therefore large-scale repulsion. There is nothing in the Particle Data Book that would do this. Neither can Dark Energy likely be explained by other fashionable hypothesized, but in this context garden variety, forms of matter, like the Higgs boson, Supersymmetric or Technicolor particles, or the contemplated candidates for cold or hot Dark Matter. Thus, the existence of this new Dark Energy would have immense implications for particle physics.

The measurement of the value of *w* would clearly be of fundamental importance in starting to understanding this new form of energy. Models have already been proposed (dynamical scalar fields, including "quintessence," tracker fields, etc.) that can be distinguished by the redshift evolution of the equation of state parameter, $w = w_0 + w_1 z$. SNAP promises to have a special capability of measuring w_0 and w_1, given a value of Ω_m and Ω_k. This will clearly be of fundamental importance for particle physics, especially since there are no ideas at this time to investigate Dark Energy employing an accelerator based approach. It is thus very likely that experimental cosmology will have a centrally important impact on progress in these fundamental issues in particle physics. In view of this, it is appropriate for particle physics in DOE and NSF to help initiate and realize the SNAP project.

In summary, future developments in fundamental physics depend strongly on the nature of the cosmic acceleration. If the acceleration is caused by a non-zero cosmological constant the origin of this non-zero value must be understood, and our theories of fundamental particles and forces must be formulated (perhaps re-formulated) in a manner consistent with this non-zero value. If the acceleration is caused by some other form of dark energy, then the dark energy must be integrated into understanding other matter and forces in nature. All these topics lie at the center of DOE high energy physics research.

The SNAP project provides the best opportunity to determine the nature of the cosmic acceleration, and optimizes both the maturity of the method and impact on the fundamental questions. This point is stated broadly in the NRC Turner Report, and was corroborated by detailed presentations and discussion during this review. Specifically, the SNAP project will determine the equation of state of the dark energy, as well as the time dependence of the equation of state. The targeted SNAP data product will determine these quantities sufficiently to maximize discriminatory power among the different explanations of the cosmic acceleration. Consequently, the SNAP project stands to have a great impact on some of the most exiting problems facing fundamental physics.

2.2.2 Mission Need

As part of the SNAP mission definition and in response to the January 2001 DOE review, the SNAP team has studied the ability of other ground-based and space-based facilities to accomplish the supernova survey. In general, the team found that ground-based facilities were unable to observe a sufficient number of high redshift SNeIa to constrain w and w' nearly as well as SNAP. Conversely, observatories such as Hubble Space Telescope and NGST do not have wide field imaging capabilities and are thus unable to observe and follow a sufficient number of supernovae to adequately define the supernovae Hubble diagram. The team found similar results for combinations of ground and space-based facilities (excluding SNAP). Weather and the limited continuous observing zones about the celestial poles constrain the ability of ground-based observatories to provide prompt spectrographic follow-up on SNAP supernovae. Limited accessibility and instrumental capabilities argue against Hubble and NGST being used for a similar function. (The SNAP mission requires 2000 visible and infrared spectra during the 2.5-year primary mission.)

Based upon the SNAP science team's simulations and our own experience, the committee believes that SNAP is *uniquely* capable of accomplishing a supernova survey that can adequately constrain the dark energy equation of state. Other facilities will provide a preliminary estimate for w if one assumes that $w' = 0$ as a prior. But only SNAP provides the necessary wavelength coverage, number of targets, and control of systematics to provide a quantitative result for w and w'. Other independent data are critical for meeting these goals. The Committee agrees with the project that reasonable priors on Ω_m (potentially from a variety of sources) or data from the upcoming PLANCK mission will provide complementary cosmological constraints that would greatly enhance the value of the SNAP results.

2.2.3 Instruments and Observing Plan

Since the January 2001 DOE review, SNAP has refined the focal plane camera and visible-NIR camera. The current camera design places a matrix of CCD (charge-coupled device for optical wavelengths) and HgCdTe (Mercury Cadmium Telluride detectors for near infrared wavelengths) detectors, each with a dedicated filter(s), in the focal plane. This design necessitated changes to the observing strategy but provides excellent control of instrumental systematics (each field is observed by four independent sets of filter-detector combinations during the year). The spectrograph features a 3" x 3" image slicer, low spectral resolution (R ~100), and two spectrographic arms for the visible (CCD) and NIR (HgCdTe). The designs of the camera and the spectrograph are driven entirely by the SNAP supernova search. It is believed that these instruments will accomplish the SNAP mission goals and are essential to the success of the mission.

The SNAP science team is still refining the details of the observing plan. They have selected target regions of low galactic extinction and have adopted the four-day cadence for "mowing" the fields. During the R&D phase, the project will develop a baseline strategy for inserting spectrographic observations and explore potential impacts on the quality of the observed supernova light curves. This is also the appropriate phase to study the impact of small failures (loss of single detectors, etc.) The Committee feels that the design of the observing strategy is sufficient for this phase of the project (trade-off studies and the setting of initial requirements.)

2.2.4 Response to the January 2001 DOE Review

The SNAP collaboration has made adequate responses to the recommendations of the January 2001 DOE review.

The need for high redshift ($z>1.5$) SNeIa was studied and established (report by E. Linder). Simulations showed the importance of these SNeIa in distinguishing dark energy models. This need then drives the need for good IR imaging and spectral coverage and is a main reason the project must be done from space.

As recommended, and as discussed in the "Findings" section, much work was done developing a simulation tool, applying it to optimize the mission, and comparing it with alternatives. The direct comparison of SNAP to ground based missions was done under varying assumptions. In all cases, the clear superiority of SNAP's approach was verified. While other facilities, such as NGST and ground-based telescopes, can be useful in some cases, the simulations show that they are not good replacements for any of the SNAP instruments. Ground-based instruments cannot get a large sample of high quality $0.9<z<1.7$ SNeIa. The slew and settling time of NGST makes it inefficient for obtaining many $z<1.7$ SneIa. Follow-up by a ground-based telescope is difficult for much of the year for SNAP's fields.

As recommended, the team considered descoping the SNAP instruments and significant degradation in both statistical and systematic errors was found. The suite of instruments proposed is a good match to the requirement for a large, uniform sample of SNeIa out to $z=1.7$, with high quality spectra, well-sampled light curves, and adequate control of systematics.

As recommended, SNAP further studied the photometric calibration. The photometric calibration requirements/estimates are now two percent in optical, three percent in NIR, and there is a four percent relative float between optical and NIR. The effects of these calibration errors were included in the simulations of SNAP's science output. The Committee believes that this precision is possible to obtain. During the next phase the project will produce a calibration plan to achieve them.

In response to the recommendation to place the NIR imager at higher priority, the collaboration increased the HgCdTe detector area to equal that of the CCD area. This change has improved the instrument and is incorporated in the end-to-end simulations.

2.2.5 R&D Readiness

The science optimization and simulation studies presented at this review were of sufficient extent and depth that the Committee feels that SNAP is ready to start the R&D phase. The funding requested for the science study team in the R&D budget appears to be appropriate to complete the required studies.

2.2.6 Other Opportunities

After SNAP has accomplished its main SNeIa survey, it will remain a unique instrument and could be used for many other very high priority scientific studies. While the guest observer program discussed by the collaboration is not an essential part of the current SNAP mission, the cost of such a program is probably very small compared to its benefit to the scientific community.

2.3 Recommendations

1. The need for a space-based, large field of view mission like SNAP to elucidate the nature of the Dark Energy via the study of Type Ia supernovae has been convincingly established.

2. The proposed instruments and observing strategy are appropriate and sufficient to complete the scientific objectives of the mission.

3. The detailed simulations, optimizations, and comparisons with ground-based facilities that were completed by SNAP and on which the above two conclusions are based should be published as soon as practical so they may be viewed by the wider community.

4. The R&D effort necessary to move this project forward should be pursued with all possible speed.

5. The studies of weak lensing and other topics relevant to cosmological parameters with SNAP should be pursued further during the R&D period.

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3. SPACE SYSTEMS (WBS 1.3, 2.1, 2.3.5, 4.0)

3.1 Findings

3.1.1 Attitude Control

The SNAP project team is aware that the pointing requirements are the biggest spacecraft issue and is doing the appropriate activities during the R&D phase to address them. There is some lack of clarity in the way the attitude control system (ACS) pointing requirements are stated in some of the documents and presentation materials.

The stability/jitter requirement of 0.01 arc seconds, 1 sigma, is a *control* requirement, not just a specification for isolation of disturbances by observatory design.

3.1.2 Mission Lifetime

The primary science goals can be achieved in the stated four-year mission life. A Guest Observer program that would commence after the four-year primary mission, was discussed, with no conclusive requirement, other than stating that it would be of value to the program and broader science community.

3.1.3 Ka-band Transmission

While programs may begin to use Ka-band for data transmission in the near future, ground stations and transmission equipment do not currently exist. The SNAP project team is aware of this and is expending effort to investigate options during the R&D phase.

3.1.4 Cost, Schedule, and Workforce

The overall funding profile and allocated workforce for the space systems effort seems adequate. The schedule to perform the work also is adequate.

3.1.5 R&D Phase Assessment

The activities scheduled for the R&D phase address the most critical issues and are appropriate for this stage of the project.

3.2 Comments

3.2.1 Attitude Control

The spacecraft ACS stability/jitter requirement is specified to be 0.01 arcseconds. A stability/jitter requirement is an allowable delta change in the spacecraft pointing over a specified period of time. The Committee was told that the specified period of time was the 300 seconds target exposure time. Since the period of time specified was the entire observation period, the 0.01 arcseconds specification is, in reality, a pointing control requirement and not a stability/jitter requirement. Due to the control loop response capability and the systematic errors within a body pointed spacecraft this requirement is difficult to meet. As a SNAP study showed, it can be accomplished with a fine steering mirror fast control loop within the body controlled ACS. Hence the previous committee's recommendation to keep a fine steering mirror within the ACS trade space.

It is not clear that the stability/jitter requirement was correctly communicated in the Integrated Mission Design Center (IMDC) study, nor that the correct comparisons were made when comparing the SNAP requirements to other missions with similar requirements.

The Committee believes SNAP understands the difficulty of the stringent pointing requirements and are taking the appropriate steps during their R&D phase, i.e., the ACS and structural/thermal modeling.

3.2.2 Mission Lifetime

Missions at NASA have a stated design life, used for specifying design and quality requirements. In addition, a longer goal is usually stated, to take advantage of the fact that missions usually last longer than their design life. Consumables are added to operate the observatory beyond its design life, subject to cost constraints.

3.2.3 Ka-Band Transmission

There are other programs considering using Ka-band for data downlink and may consider sharing costs to develop equipment or ground stations.

3.3 Recommendations

1. Be clear on the pointing requirements for the Attitude Control. State the requirements in a clear, consistent, and understandable way. The Committee concurs with the plan to verify the numerical values of the requirements during the R&D phase.

2. Retain the steering mirror option and include it in the ACS modeling. Include it as part of the ACS trade-off studies performed during the R&D phase, while the pointing requirements are being further defined, and the ACS configuration tradeoffs are being studied.

3. Perform a cost and complexity vs. scientific benefit trade-off study on the requirement to perform dithering.

4. Consider sizing the spacecraft consumables (e.g., propellant, solar array size, battery depth of discharge, and cycle life) to accommodate operating the observatory beyond its design life of four years, thereby enabling the support of a potential Guest Observer program after the primary objectives of the mission have been accomplished. The Committee does not recommend increasing the design lifetime, as that will incur large cost increases and the primary objectives can be accomplished within the four years. However, to take advantage of the fact that missions usually last beyond their design life, and to account for the possibility of the Guest Observer program, it should be considered to include these consumables in the designs now, to see the impact on the designs as the structural, thermal, and ACS models are being developed.

5. Investigate the possibility of sharing costs with other space programs for potential required developments for Ka-band data transmission.

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4. TELESCOPE (WBS 2.2)

4.1 Findings

The optical design is mature and represents a conservative approach. The Three Mirror Anastigmat (TMA) is a proven design.

The baseline materials are the classical zero-expansion glasses for the telescope optics and cyanate ester composites that represent the current demonstrated technology.

There was a concern that the shutter was a single point failure. The matter was addressed with a conceptual of a dual shutter, with the capability to latch a shutter from the closed state, and will be resolved in the preliminary design phase.

The four-year schedule for the optical telescope assembly (OTA) construction, assembly, and integration will require continuous monitoring of the contractors and has no slack.

The Fast Steering Mirror (secondary mirror) was addressed in the answers to the January 2001 DOE review report. It should remain in the trade space for possible use for fine guiding and dithering.

4.2 Comments

The design of the OTA is classical and proven—there are no technology development issues.

The primary mirror material should be limited to the zero-expansions materials presented. Silicon Carbide (SiC) is not as mature in this aperture. With the schedule as it exists, SiC does not deserve additional consideration.

Among the zero-expansion materials for the primary mirror Corning's Ultra-Low Expansion (ULE) glass has two advantages over Schott's Zerodur and these are lower mass and less depth to the mirror. The latter is important because it allows more room for the optics behind the primary mirror. Both benefits relate to the mirrors construction. The ULE mirrors can be fused or frit bonded together allowing for a rear facesheet (known as a closed back mirror). These processes are typically not used for Zerodur. As a result for equivalent bending stiffness, ULE mirrors are lighter and thinner than Zerodur.

An error budget should be prepared for the optical testing of each component, and the integrated telescope.

Manpower and funding appears reasonable to reach Critical Decision 1, Approve Preliminary Baseline Range.

5. INSTRUMENT (WBS 2.3)

5.1 Findings

The SNAP project team proposes two instruments, an imager, and a spectrograph. Both instruments will have optical and near infrared detectors that are sensitive from 0.35 to 1.7 microns. The imager has a large field of view (0.7 sq. deg) that is filled with 36 CCDs (3.5K x 3.5K, 10.5 micron pixels) and 36 near infrared detectors (2K x 2K, 18 micron pixels) that will image the sky through nine filters, sampling the B-band of the rest frame supernova for redshifts of z=0.3 to z=1.7. The spectrograph is an integral field unit with 20 by 20 spatial pixels of 0.15 arc sec size whose spectra are sampled with a resolution of 100. The baseline plan has the same type of detectors for the imager and the spectrograph. The CCDs are planned to be thick p-channel devices that are produced by a combination of a commercial silicon foundry and LBNL. The infrared detector baseline is the Hawaii devices being produced by the Rockwell Science Center. In order to operate the 900 output channels of the detectors with low power, the SNAP team proposes use of specially designed ASICs (application specific integrated circuits) for processing the video signals from the detectors.

5.2 Comments

The detector system being developed for SNAP is the most ambitious detector focal plane ever proposed, for ground or space. In addition to the size and complexity of the focal plane, the project is also developing the CCDs for the focal plane. In comparison to the other aspects of the mission, the detector systems are the highest risk items of the mission. The detector development plan is going in the correct direction but the development plan is optimistic and the team has presented a success-oriented schedule. To bring the detectors up to the technical readiness level of the other aspects of the mission and to keep the overall project schedule, the detector development should be given highest priority within SNAP.

The Committee believes that the best way to put the detector work in perspective with the rest of this space mission is to say that this spacecraft is a “detector project with a telescope attached.”

The detector development and production is on the critical path for the mission. After all development is completed, we estimate that the production and testing of the detectors will take two to three years. Another year will be needed to integrate and test the complete detector system. Since the detector procurement and system integration time period is comparable to that for the telescope (which was presented as the longest lead time item), the detector procurement should be initiated as early as possible in the project. Thus, the goal of the R&D phase should be to take the detectors completely through the development cycle, an ambitious goal for a period of one and one half to two years.

Given the criticality of the detector development, it is prudent for the project to develop second source suppliers for both types of detectors, and our major recommendations focus on this aspect of the R&D phase. The plans presented by the SNAP team did not include pursuit of the second source options. The second source for infrared detectors is obvious since there are two leading suppliers of devices that SNAP is seeking. The CCD development and production has three possible scenarios as shown in Figure 5-1.

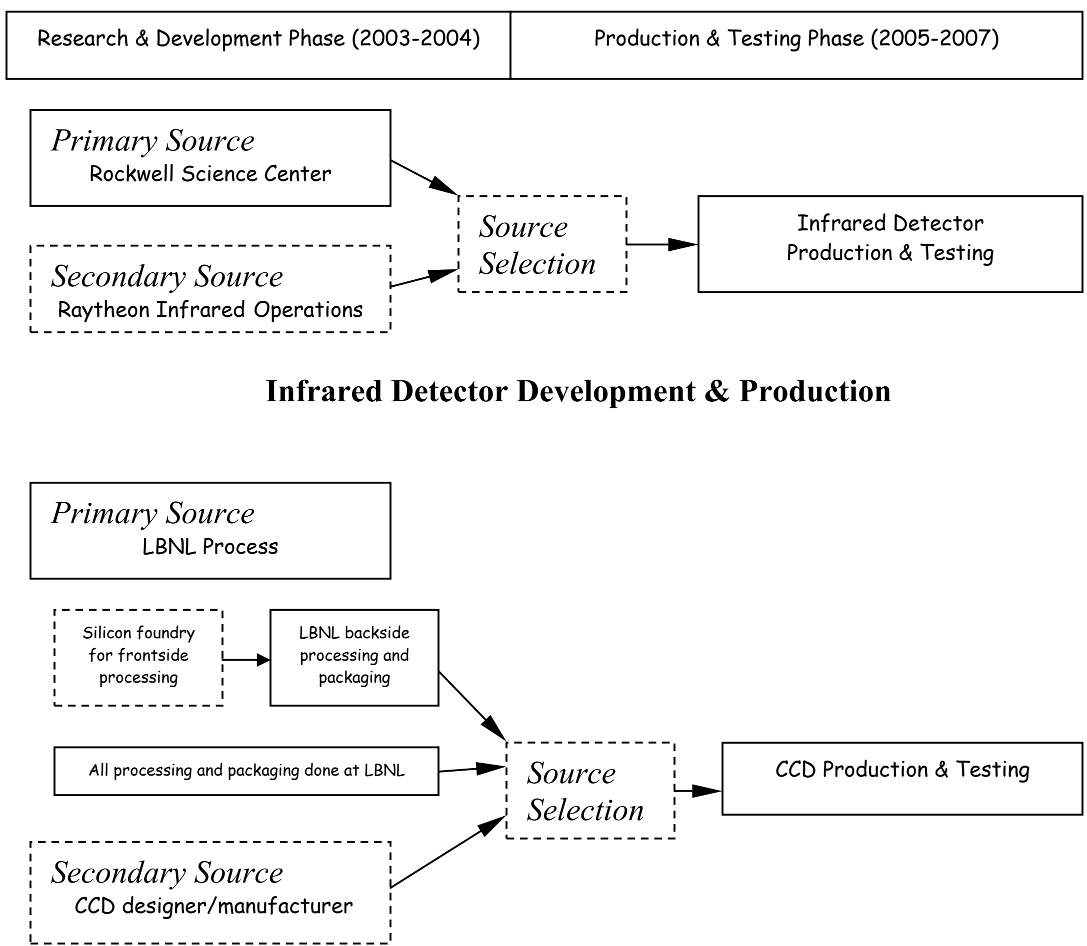

Figure 5-1. CCD Development and Production

The Committee's recommendations are denoted by boxes with dashed lines. The Committee's primary recommendation is that a second source should be investigated for each type of detector. For the CCD development, more attention needs to be given to the relationship with the silicon foundry (Dalsa) that is commercializing the LBNL process for the frontside processing of the detector wafers. Note that the primary source that is being developed for the CCDs is composed of three steps: frontside processing at Dalsa, wafer thinning by a third party (not shown in the diagram), and backside processing and packaging by LBNL. The first backup option is for LBNL to undertake all of the processing by itself, something that would require a significant enhancement of the production capability of LBNL. There are CCD designers and manufacturers that could independently develop and produce an appropriate CCD for the SNAP mission (e.g., MIT Lincoln Laboratory). During the R&D phase of SNAP, it may be prudent to have a backup CCD designed and one lot of CCDs produced and tested so that a backup option is ready at the end of 2004. (Note that a four-side buttable package does not need to be developed for the backup option during the R&D phase.) Also, the CCDs produced by a different process may not have the features of the LBNL process that are desired for SNAP (very high QE for 900-1000 nm, tight point spread function, radiation hardness).

The detector teams, infrared and CCD, need more resources than requested due to the success-oriented nature of the plan, if the schedule is to be achieved. The infrared expertise within the team is not at the level required for a mission of this magnitude and attention should be given to strengthening the infrared detector expertise within the SNAP project, if necessary by bringing in collaborators with experience in infrared detectors.

5.2.1 Charged-Coupled Devices

The charged-coupled device (CCD) development is primarily under the control of LBNL. While at first blush this would appear to be comforting, on closer inspection it raises concerns. There is a large amount of work to be done to complete the development of the CCDs, including: 1) new CCD designs and iteration of the designs after testing, 2) transfer of the fabrication process to a commercial foundry, 3) design and implementation of a number of new features in the devices, 4) debugging of the thinning and backside processing, 5) development and testing of a new four-side-buttable package, and 6) development of filter technology to be placed directly on the CCD surface. In addition, the CCD team needs to develop a new generation CCD testbench that can measure quantum efficiency and automatically test and optimize the devices; needed both for development of the CCDs and in preparation for large scale testing during the procurement. In addition, the CCD team has many critical roles being filled by a single person. Steve Holland is the CCD designer, the liaison to the commercial foundry and one of two persons that works in the LBNL wafer processing facility. SNAP should consider hiring a CCD expert to work closely with Steve Holland for information transfer and off-loading of some of the current workload.

One of the new features that is being attempted with the CCDs is modification of the design to produce a tighter point spread function (PSF). The tighter PSF is produced by significantly increasing the bias voltage on the backside of the device, a design and operation change that is difficult. While this is an admirable goal, the Committee was not certain this effort and risk is necessary since a wider PSF affects the blue band measurements most—the blue band the signal will be the most intense and will not be adversely affected by a slightly wider PSF.

To the Committee's knowledge, no one has ever placed scientific quality interference filters directly on science quality CCDs. There is significant effort and testing required to do this properly, if it can be done at all, and the staffing plan does not seem to adequately allow for the effort required in this area.

The CCD team should more proactively engage the ground-based telescope community in the testing of the SNAP CCDs. The SNAP project team can get a large number of very experienced and talented people testing SNAP CCDs at no cost to the project via a distribution of CCDs to observatories for use in their instruments. Distribution of detectors to ground-based telescopes was instrumental in the success of the first Hubble Space Telescope detectors. The distribution of CCDs should proceed as soon as feasible, but should commence no later than the end of 2002. In undertaking a CCD distribution, the Committee recommends that a SNAP acknowledgement be required in all papers published with data from SNAP CCDs. Prior to the distribution of CCDs, LBNL must address the question of which organizations are given access—specifically, should devices be distributed to foreign observatories?

The LBNL CCDs have not reached full maturity and although the Committee was very impressed by the quality of the LBNL CCD team, it would be prudent to investigate an entirely different source of CCDs; n-type CCDs designed, produced, and packaged by a third party manufacturer. A backup design and fabrication run could be accomplished during the R&D phase.

5.2.2 Infrared

The infrared detector development is riding on the back of the much larger efforts being undertaken for Hubble Space Telescope (WFC3), NGST and ground-based telescopes (ESO, CFHT, Gemini, etc.). The detector team should let those groups lead the way but should develop infrared detector expertise and follow the developments by procuring and characterizing some devices.

The 1.7 micron cut-off HgCdTe arrays for Hubble Space Telescope /WFC3, designed to be operable at the relatively warm focal plane temperatures achievable for WFC3 (and also for SNAP) currently face significant technical challenges: significant instability (hysteresis) for the high QE parts that have been fabricated, as well as excessive read noise. The WFC3 project will push very hard on these performance parameters, but the SNAP project team should be aware that these issues are not yet resolved and should be monitored closely. SNAP performance requirements should be carefully thought through and clearly articulated. There is concern about the readout noise level of the newest Rockwell detectors, and the SNAP team should clearly identify what noise level is required. The SNAP team can have confidence that the noise performance will be pushed very hard by the project listed above, and there should not be significant concern about the readout noise at this time. A second possible source of infrared detectors that should be investigated is Raytheon Infrared Operations (RIO).

The SNAP infrared detector team is only beginning to set up a laboratory for testing infrared devices, a process that is harder than would first appear, especially if the goal is to test the detectors at the highest level. The SNAP team should ensure that they have within their collaboration an infrared testing facility equal to those at other leading organizations (e.g., ESO).

5.2.3 Spectrograph

The spectrograph design is efficient, the team from France is very good and there appear to be no major concerns with the spectrograph conceptual design. There is the possibility of a custom-designed CCD for the optical arm of the spectrograph, with the optimal size, shape, and number of pixels. The spectrographic CCD could incorporate frame transfer that would provide two important capabilities: 1) shutterless operation and, 2) very slow readout during subsequent exposure to achieve lowest noise. With the custom-designed CCD, the spectrograph could be operated in shutterless mode, either as primary mode of operation or as backup in case of shutter failure.

5.2.4 Electronics

The electronics development is well planned and adequately staffed, provided the persons listed in the plan are available as scheduled to do the work. A conceptual design of the front-end ASIC (application specific integrated circuit) exists and although challenging with respect to noise performance, is well within the expertise of the designers involved. An ASIC technology has already been evaluated and seems to satisfy the SNAP performance requirements regarding radiation, noise, and operating temperature.

The preliminary plan for the overall electronics system is to store minimally processed data in a solid-state recorder and transmit the data to ground once per orbit via a high-bandwidth K-band datalink. The Committee thinks this concept is good and has many advantages.

The Committee felt that the power budget allowed for the electronics system seemed low and the SNAP electronics team should investigate whether the power and thermal system can provide more power if needed.

The design team should include analysis of electromagnetic interference and shielding requirements during the design phase.

The failure modes and failure rates of the detectors and associated electronic system need to be investigated. For example, how many channels or even sections of the system can be lost and still meet the scientific mission goals? This answer will affect the partitioning and redundancy of the system electronics.

The design of the power supply system should be included in the conceptual design phase, since some of the bias supplies, as well as the low-noise, low-voltage supplies may have to be a full-custom design.

5.3 Recommendations

1. The development of the detectors should be given the highest priority of the entire SNAP project during the R&D phase.

2. Strengthen the infrared detector development effort, if necessary by bringing in collaborators with experience in infrared detectors.

3. Strengthen the CCD team to have a higher probability of meeting the schedule.

4. Give additional attention to the ongoing relationship with the silicon foundry that is commercializing the LBNL CCD process.

5. Investigate an n-type CCD designer / manufacturer as an independent backup option.

6. Revisit the requirement for the presently planned point spread function (PSF) for the CCD.

7. Upgrade the CCD test facility to provide timely feedback during the development cycle.

8. Revisit the plan for depositing filters directly on the detectors.

9. Distribute the SNAP CCDs to several more ground-based telescopes to increase testing of the detectors.

10. Investigate a second source vendor of infrared detectors.

11. Investigate a custom-designed CCD with the optimal format for the spectrograph.

12. Study the feasibility of eliminating the shutters from the spectrograph.

13. Address the failure modes and failure rates of the detector electronic system, including the detectors.

14. Perform as planned a system test with a prototype ASIC (application specific integrated circuit) and a CCD to verify that 16-bit dynamic range can be obtained.

15. Develop a calibration plan for the electronics system, especially in light of the planned (and supported by the committee) use of an on-chip multi-range ADC concept.

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6. GROUND SEGMENT/COMPUTING (WBS 3.1, 3.2)

6.1 Findings and Comments

6.1.1 Mission Operations (WBS 3.1)

Development of the Mission Operations support is based on the foundation of the Berkeley Ground Station (BGS). The BGS seems to keep itself, its equipment, and software, up-to-date. The also have a good procedure for training operators, a great deal of experience, plans for end-to-end test, etc. BGS will form an excellent base for support of the SNAP mission.

The number of R&D issues is small and includes: 1) Ka band antenna (upgrade or new), 2) secondary downlink and method for transferring data to LBNL, and 3) determination of amount of buffering and required hardware in case of failure or unavailability of link to SOC. R&D issues are correctly identified and the resources requested should be able to accomplish the few R&D goals.

6.1.2 Science Operations Center (WBS 3.2)

Scope Definition. While the task of defining the project scope has begun, much work remains to be done. The goal is to get a credible scope, cost, and schedule for the data processing and analysis component of the Conceptual Design Report. The human resources assigned to this task are about 3.5 full-time equivalents (FTE) per year.

Project Definition. Science Operations Center/Software is now included as a high-level subproject of the R&D project and will be treated as such in the full SNAP construction project. A subproject leader is in place, other key management roles have been identified and filled, and personnel have been identified to carry out the R&D. A WBS for the R&D subproject has been developed.

Fast Simulation Effort. The SNAPFast effort has succeeded and has helped the SNAP project team understand many key requirements and design issues. It has also helped them understand the capabilities of other approaches to studying SNeIa.

Detailed Simulation Effort. The next phase of simulation is a detailed pixel level simulation of the instrument, which is necessary both to help make key design choices and to test the scientific software. The effort allocated to this task is about 3.5 FTEs.

Hardware is not a major problem. The project could use Parallel Distributed Systems Facility (PDSF)/National Energy Research Scientific Computing Center today. The PDSF facility is modernized every three years. Also, LBNL also now supports "mini farms/facilities" if SNAP needs a dedicated facility.

Staffing Levels. The project has about 6.5 FTEs per year for the R&D part of the Science Software. They have names next to all "slots" except one graduate student to be named later. The average duty factor of people involved is slightly less then 0.5. But a good part, nearly half, of these people (and half the effort) will likely be committed to writing the detailed simulation, so the resources available for this scope definition are only 3-3.5 FTEs per year.

It is highly appropriate that Science Operations Software be treated as a major aspect of SNAP and be managed as part of the project. Effective software will be required both to optimize the final design of SNAP and, in operation, to realize the full potential of the telescope, especially through calibration and control and understanding of systematics. Failure to acknowledge the complexity and cost of the software effort has caused serious problems for similar projects.

Depending on how much software needs to be written as opposed to being obtained from elsewhere, the final project could be fairly small or very large. If most software had to be developed from scratch, the cost and size of this project can be estimated by comparison with similar projects and could well exceed $20 million and require 25 FTEs for several years; such projects have proved extremely hard to manage successfully.

Scope Definition. Defining the scope of the scientific software project is a key goal. It is a difficult but necessary job. To get accurate buy-steal/adapt/build decisions, which the Committee recommends, will require actually trying various codes to see how much functionality is missing and how much effort would be required before they met requirements.

Many of the decisions will depend on who will be available for programming. Good people are needed, to keep the enterprise centered on scientific rather than computer science goals. The project manager described needed staff as: 1) scientists who also do programming, and 2) programmers cognizant of the scientific aspects of the project. The Committee concurs with this statement.

Data access is an important aspect of the scope definition. How will data access be handled for science for the group and for wider dissemination? This is important for doing the science and is a place where other projects have had problems. The SNAP project needs to decide whether the data distribution plan should be designed to only handle the main SNeIa dataset or also to support the ancillary science.

The Committee also observed that in evaluating "external" code for possible use in SNAP, due attention should be paid to maintenance and support issues and lifetime costs. It is hard to know whether 3.5 FTEs per year is adequate to the task of defining the scope of the software.

The only way to know if an instrument is working is to push it to its limits. The Committee encourages the SNAP software team not to concentrate too single-mindedly on the photometry of SneIa. If the codes are designed only to achieve SNAP's core scientific goal, there is concern that subtle problems in the data or processing that have shown up in a broader scientific analysis may not be found.

The project leader believes that 3.5 FTEs are sufficient to complete the detailed simulation program in about one year if everything goes well. He would feel more comfortable if there were about 50 percent more effort. If the software is not completed in roughly a year, it may not be useful for the development of the Conceptual Design Report. It is, in any case, needed for testing.

In order to be useful in the design phase, the simulation development must be paralleled by an effort to produce realistic analysis software. This does not appear to be part of the plan and we could not tell whether the existing science code is adequate.

6.2 Recommendations

1. Strive to control the size and scope of the software effort by taking advantage of work done elsewhere.

2. Develop a complete, prioritized list of software tasks. The project should identify a list of the most promising potential external sources of code for each task and make a plan for evaluating these packages to see which can be used or adapted for use. The project should also attempt to make an estimate of the level of effort required to adopt, adapt or build from scratch. A report on this activity should be one deliverable for the next review.

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7. COST, SCHEDULE, and FUNDING (WBS 1.1)

7.1 Findings

The SNAP project has made substantial progress in developing its R&D cost estimate since the January 2001 DOE review. The estimate has been developed in accordance with a well-defined hierarchical work breakdown structure (WBS). The various subproject estimates are collected and organized in a standardized cost control system that facilitates drill–down to lower levels in the WBS and takes into account appropriate wage rates, overheads, and escalation rates.

The project currently estimates the costs (in thousands) of the R&D phase over the next two fiscal years (FY 2003, FY 2004) is shown in Table 7-1.

Table 7-1. R&D Phase Estimate

WBS	Description	FY03	FY04	Total
1.1	Management	599	808	1,407
1.2	Science	543	935	1,479
1.3	Systems Eng	871	1,479	2,350
2.2	Telescope	479	908	1,387
2.3	Instrumentation	3,445	5,419	8,864
2.5	Calibration	434	581	1,015
3.2	Science Ops	535	556	1,091
	SubTotal	**6,907**	**10,685**	**17,592**
1.0	Contingency (34%)	593	5,315	5,908
	Total	**7,500**	**16,000**	**23,500**

Contingency for the project has been estimated by reviewing the cost estimates at appropriate levels of the WBS and typically applying one of two values: 30 percent for engineering estimates or 40 percent for physicist estimates. Separate (and potentially different) contingencies on equipment and labor were not assumed. Contingency dollars were determined after the addition of any general and administrative (G&A) costs to the base costs. An effective contingency of 34 percent or $5,908 K resulted. The project has allocated this contingency at $593 K in FY 2003 and $5,315 K in FY 2004.

Within the proposed two years of R&D funding, there is about an eighteen-month period to develop the Conceptual Design Report, starting in January 2003 and concluding in August 2004. The first three months of FY03 assume continued R&D funding at current (FY02) levels. FY04 concludes with two months of R&D funding corresponding to approximately 45 FTEs on-project and eight FTEs base program and $650 K per month to maintain the workforce for the transition into the preliminary design phase.

There are two specific exclusions from the $23.5 million R&D cost estimate that contribute significant value to the project but are not considered part of the R&D costs. These are:

a. Certain DOE/HEP base program labor and equipment costs.
b. In-kind contributions to spectrograph development from French institutions that are members of the SNAP collaboration.

Preliminary R&D schedules using MicroSoft Project exist or are being developed for each Level 2 system. These schedules have not been resource-loaded.

7.2 Comments

The level of detail of the R&D cost estimate is appropriate for a project in the pre-conceptual planning phase. As the cost estimate is developed further during later project phases, the project office should consolidate the backup documentation that contributes to the basis of estimate (BOE).

The overall contingency, 34 percent, is judged to be adequate, though not generous, for a project about to embark on a conceptual design phase that involves significant R&D. The risks and uncertainties have been adequately identified.

The asymmetric allocation of contingency between FY 2003 and FY 2004 implies that the work in FY 2003 is very well defined and essentially all the uncertainties are in FY 2004.

The proposed R&D funding profile during the next two fiscal years seems reasonable and allows for smooth transitions into and out of the Conceptual Design Review phase. Failure to secure the necessary funding according to the plan could adversely impact the schedule and/or increase the risk and, potentially, the final cost of the project.

The lack of resource loading in the subsystem schedules is not considered to be a problem at the present time, given the current R&D scope and level of schedule detail. However, as the project progresses to its subsequent phases, the proper resource-loading of a comprehensive and more detailed schedule should help in projecting resource needs, identifying possible over-allocations, and assessing any resulting schedule impacts.

7.3 Recommendation

1. The project should pursue the requested R&D funding through the DOE/HEP program office and other potential funding sources.

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8. PROJECT MANAGEMENT (WBS 1.1)

8.1 Findings and Comments

H. Heetderks has taken over the Project Manager position and R. DiGennaro has become Deputy Project Manager.

NASA is not currently part of the SNAP Collaboration.

SNAP support now includes a significant contribution from LBNL funds that cannot be continued into FY 2003.

SNAP is reaching out to others with relevant experience, such as the Space Telescope Science Institute, to learn appropriately and possibly enlist collaborators.

Project Management of the R&D Phase include:

- The new Project Managers brings extensive relevant experience to bear.
- The level of engineering support seems excellent.
- The manpower level of the management appears appropriate
- The management tools for cost and schedule development and control seem adequate. Management roles and responsibilities are well defined. R&D deliverables have been defined, and if achieved, will result in a successful R&D phase. However, any significant shortfall to the funding request would jeopardize these goals and either delay the project or increase risk.
- The currently formulated SNAP Project Management is well matched and appropriate to the SNAP R&D phase.

The GLAST project at SLAC has generated some relevant experience as a DOE laboratory led satellite project. Some of their experience may be useful to SNAP. SNAP has benefited by a tightly focused science program to keep technical problems and costs at a reasonable level. NASA might contribute to the success of SNAP with several key technologies and be valuable collaborators on the science.

8.2 Recommendations

1. Establish a laboratory-to-laboratory Memorandum of Understanding for the Spectrograph R&D effort as soon as reasonable. DOE should begin planning with CNES for a timely agreement for subsequent work.

2. The SNAP Science Principal Investigators (PI's), DOE, and NASA should establish discussions regarding collaboration on SNAP.

3. Continue building the collaboration to enlist those with important interest and experience in the community.

4. LBNL management should continue to provide support and oversight to SNAP.